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Ref: (a) Dahlgren Project Order #PO-1-0020 of 14 June 1961

Encl: (1) Quarterly Progress Report for the period 1 April to 30 June 1963 on subject task

1. Enclosure (1) is forwarded herewith in compliance with reference (a).

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QUARTERLY PROGRESS REPORT ON GUIDED MISSILE PROPULSION SYSTEM HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO) RF CHARACTERISTICS OF ELECTRO-EXPLOSIVE DEVICES

TASK NOL-443

Period Covered
1 April 1963-30 June 1963

Explosion Dynamics Division
Explosions Research Department

REPORT ON PROGRESS OF GUIDED MISSILE PROPULSION SYSTEM
HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO)
RF CHARACTERISTICS OF ELECTRO-EXPLOSIVE DEVICES
FOR THE QUARTER ENDING 30 JUNE 1963
TASK NOL-443

1. PROGRESS DURING THE PERIOD

a. Sorting of EED's. The correlationsof γ with M (data obtained by the two-temperature method) and of C_p with M (C_p data obtained from 50 microsecond constant current pulse response) were computed for the 210 Squibs Mk 1 Mod 0. Assuming a linear relationship it was found that

$$\gamma = 0.194M + 3.25; \text{ coefficient of correlation} = 0.459$$

and

$$C_p = 0.00334M + 0.695; \text{ coefficient of correlation} = 0.752$$

where γ is expressed in microwatts/°C,
C_p in microjoules/°C,
M in micro-ohms/°C.

The correlation coefficients show that the magnitudes of γ and C_p are not independent of the magnitude of M. This does not necessarily mean that there are causal relationships between these parameters. One immediate consequence of a high correlation is that a sort on C_p would give nearly the same ordering or ranking of units as a sort on M. Yet the electro-thermal theory says that there ought to be a negative correlation between adiabatic sensitivity and C_p, i.e., a small-C_p unit should be more sensitive than a large-C_p unit. As will appear later in this report, we have observed the theoretical correlation between C_p and firing sensitivity. Consequently the meaning of the C_p with M correlation is not clear.

As stated in the previous quarterly report replicate values of γ and C_p were measured on twenty-four EED's. A determination was made of the standard error of measurement. The standard errors were 14 microwatts per degree centigrade for γ and 0.12 microjoules per degree centigrade for C_p. The error is about three per cent in each case.

It was decided that the EED's would first be sorted on γ into 3 groups on the basis of constant current response. To sort on γ alone is, however, not adequate; for two units with exactly the same γ but of different resistances would be heated to different temperatures by the same current.

Using the electro-thermal equation it is possible to devise a Figure of Merit for response to steady-state constant current as follows:

$$\gamma\theta = P(t)$$
$$= I^2R_0\ (1+\alpha\theta)$$
$$= I^2R_0 + I^2M\theta$$
$$\theta = \frac{I^2R_0}{\gamma - I^2M}$$

For a given current this expression would give the temperature elevation of the bridge wire. Sorting should be on the basis of relative temperature elevation. Using this approach the following groups were set up:

Group	Figure of Merit I = 290 ma	θ (°C)	No. of EED's in class
a	High (most sensitive)	210.5 to 272.4	56
–	Intermediate	191.1 to 210.4	62
b	Low (least sensitive)	191 to 161	54

It was expected that, from the High to the Low group, only a 3 or 4% difference in the 50% constant current firing points might be observed. The difference between the Intermediate group and either of the others might be small enough to be masked by experimental error. Therefore it was decided to split the intermediate group on the basis of C_p for firing under adiabatic conditions. The separation on C_p was made as follows:

Group	Adiabatic Response	C_p μjoules/°C	No. of EED's in class
c	Most sensitive	3.263 to 3.668	23
d	Intermediate sensitivity	3.696 to 3.895	16
e	Least sensitive	3.900 to 4.587	23

For the constant current firing (Groups a, b) a transistorized firing apparatus was used to deliver the current with a drift of less than 1 milliampere in the 10 second firing time. A storage battery supply and forced-air cooling of the transistors, Zener diodes and power resistors were employed to obtain the necessary instrument stability. A No-Go was defined as a failure-to-fire after a ten second application of current.

A separation was observed in the predicted manner. Group (a), the more sensitive one, exhibited the lesser, 50% firing, current requirement.

Group	Predicted Sensitivity	Linear Logistic Firing Points	No. of Units Tested
b	Lesser sensitivity (higher current)	95% - 282.5ma 50% - 277.0ma 5% - 271.5ma	51
a	Greater sensitivity (lower current)	95% - 274.4ma 50% - 266.8ma 5% - 259.1ma	30

The chances are less than 1 in 200 that these results could have been observed on two random samples from one population.

These results are taken as another proof of the applicability of electro-thermal models in that a separation was achieved. However it also indicates that this procedure, at least for the Mk 1 Squib which seems to have a low built-in variability, does not offer much hope for a clear cut separation of an individual from a parent population on the basis of sensitivity. The sort achieved was not widely spaced. Sensitivity of units overlapped. Further, even to achieve the sort obtained very careful measurements were necessary as described in the previous quarterly progress report.

Groups c, d, and e were fired under adiabatic conditions. Inspection of the data indicates that there will be a greater percentage sensitivity separation between c and d, and between d and e, than was observed between a and b. Although the data have not yet been fully reduced it is obvious that the separations occurred and were in the predicted directions.

In passing it should be noted that under the steady-state firing conditions, the temperatures of firing would be expected to be much lower than 450 to 500°C, in fact in the order of 210 to 250°C. The Figure of Merit calculations give an indication of this fact. Firing in process on control samples of Mk 1 Squibs is expected to yield quantitative measures of this firing temperature.

b. Electro-Thermal Phase Shift Bridge. Before the above 210 squibs were fired they were run through the electro-thermal phase shift bridge for determination of γ, C_p and τ. It was evident that the inherent experimental error (about 5 to 10%) masked the true variability of loaded units to the extent that a definitive sorting could not be expected.

On the other hand, it is quite certain that the phase shift bridge can be used to distinguish between loaded and unloaded EED's and probably units which have been made with improper bridge wire characteristics. To prove this a program is underway for fabricating and testing with the phase shift bridge EED's, some number of which will intentionally be made wrong. The group doing the testing will not be informed what has been done or how many units are bad but will try to find this out using the phase shift bridge.

c. Bartlett Data Bias. The Bartlett data collection plan as applied to EED's consists of testing at a number of fixed stimulus levels. When exactly two reversals are observed at a level testing at that level is stopped. (A reversal is a fail where fires are predominant or vice versa). It was reasoned that a bias would exist in statistical analyses where the data were collected by the Bartlett plan. Calculations were made to test this hypothesis and to determine the degree of bias, if any.

Starting with a known probability of firing it is possible using binomial statistics to calculate the probability of requiring exactly n trials to observe exactly two reversals with the second reversal occurring on the nth trial. The calculated probability as a function of n will go through a maximum. If there is no bias the maximum will occur at a value of n where (n-2)/n equals the true firing probability. Further the individual probability at each n can be summed to generate a cumulative probability curve which gives the probability of observing the second reversal in n trials or less. If there is no bias the 50 per cent probability point on the cumulative curve will again occur at the point where (n-2)/n equals the true firing probability.

The calculated results are shown in Tables 1 and 2. In Table 1 the true response is 97.5 per cent. The last two columns of Table 1 give the individual and cumulative probabilities. It can be seen that bias does exist because the maximum individual probability (column 3) occurs at n = 40 to 41 corresponding to a firing probability of only ~ 95 per cent. Likewise for the cumulative curve the 50 per cent point occurs at ~ the 97 per cent point. Table 2 shows the firing level estimated by the Bartlett plan vs the true level for different firing probabilities along with the calculated lower 95 per cent limit (i.e. values less than this will be calculated from the Bartlett data 5 times in 100).

The data can be further analyzed to show that the true firing probability in general will be underestimated 12 times out of 20.

d. <u>9KMC Firing.</u> A new 9KMC source has been assembled and is now operating. The anomalous modes of initiation reported in NOLTR 62-77 have been duplicated. Other ways of energizing the EED at 9KMC are being sought to determine whether the anomalies are to be expected at this frequency or are a unique consequence of the particular experimental apparatus.

e. <u>Non-Parametric Statistics.</u> Non-parametric statistics are being looked into for treating sensitivity data. It is expected that such statistics can be used to make safety and reliability estimates without the knowledge of the specific distribution function involved, as long as the distribution adheres to certain mathematical relationships.

2. PLANS FOR NEXT PERIOD.

The adiabatic pulse firing data on groups c, d, and e will be processed. Steady-state and adiabatic pulse firing will be carried out on two control groups (40 units in each group) of Squibs Mk 1 Mod 0. The phase shift bridge evaluation, 9KMC firing, and non-parametric statistical studies will be continued.

Table 1

Bartlett Bias Computations for a True Probability of 97.5 (all probabilities given in per cent)

a	b	c	d
Number of Trials: n	Observed Response n-2/n	The probability of observing 2 reversals out of exactly b trials	out of n trials or less
2	0	0.0625	0.0625
3	33.333	0.1219	0.1844
4	50.000	0.1782	0.3626
5	60.000	0.2317	0.5943
38	94.737	0.9295	24.56
39	94.872	0.9308	25.49
40	95.000	0.9314	26.42
41	95.122	0.9314	27.35
42	95.238	0.9308	28.28
43	95.349	0.9297	29.21
65	96.923	0.8116	48.56
66	96.970	0.8037	49.37
67	97.015	0.7957	50.16
68	97.059	0.7875	50.95
78	97.436	0.7026	58.36
79	97.468	0.6940	59.06
80	97.500	0.6853	59.74
81	97.531	0.6766	60.42
82	97.561	0.6679	61.09

Table 2

True Response and Estimated Response Using Bartlett Plan

True Probability	The level that would be estimated by Bartlett plan Median (50% probability)	Lower 95% limit
90	87.87	45
95	93.98	72
97.5	97.00	86
99	98.81	94.4

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